Earth Science Technology Program (ESTP)

Systems Engineering Seminar

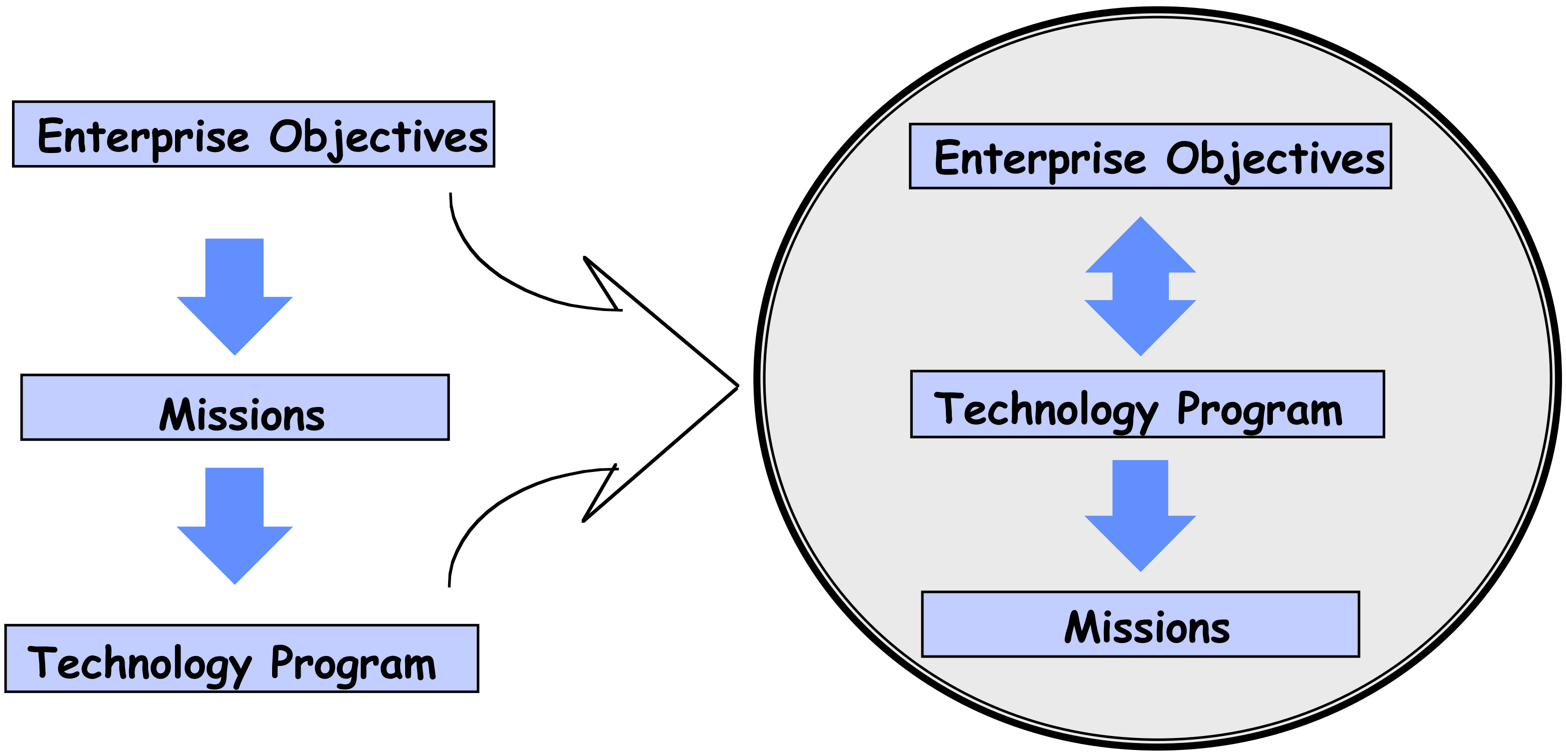
June 5, 2001

George J. Komar
Program Manager
301-286-0007

Background

- The Earth Science Biennial Review (June 1997) recommended that future missions be implemented with shorter development time and using the best suitable technology.
- The resulting plan included the establishment of a flexible, science-driven technology strategy that would develop very specific technologies and provide a broad portfolio of emerging technologies for infusion into a range of missions.
- To meet these challenges the Earth Science Technology Program was established and the Earth Science Technology Office (ESTO) created in March 1998.

Shift from "Technology Derived from Missions" to "Missions Enabled by Technology"



Enterprise objectives established

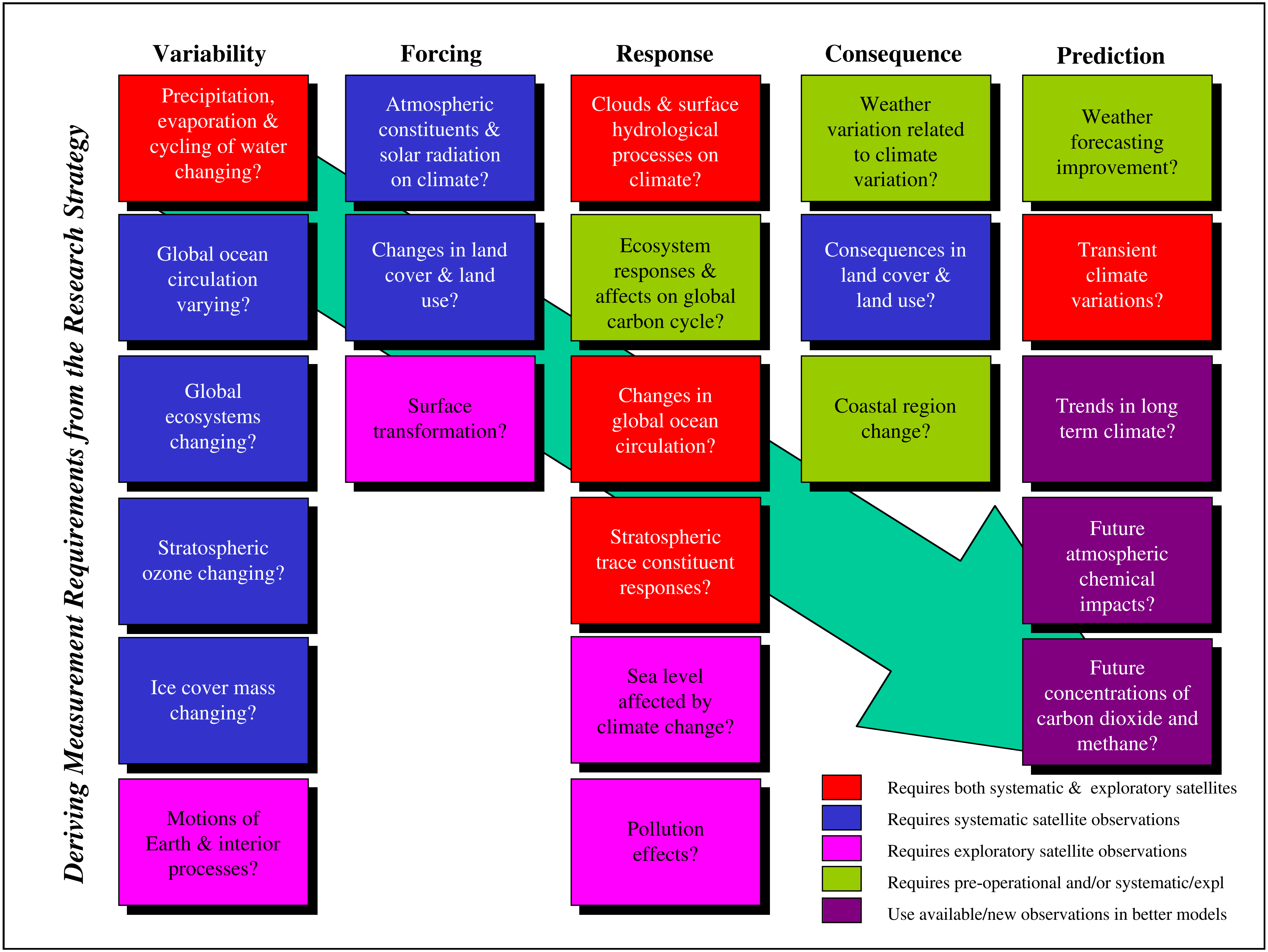
Missions sets derived from Enterprise Objectives

Technology programs derived from mission requirements

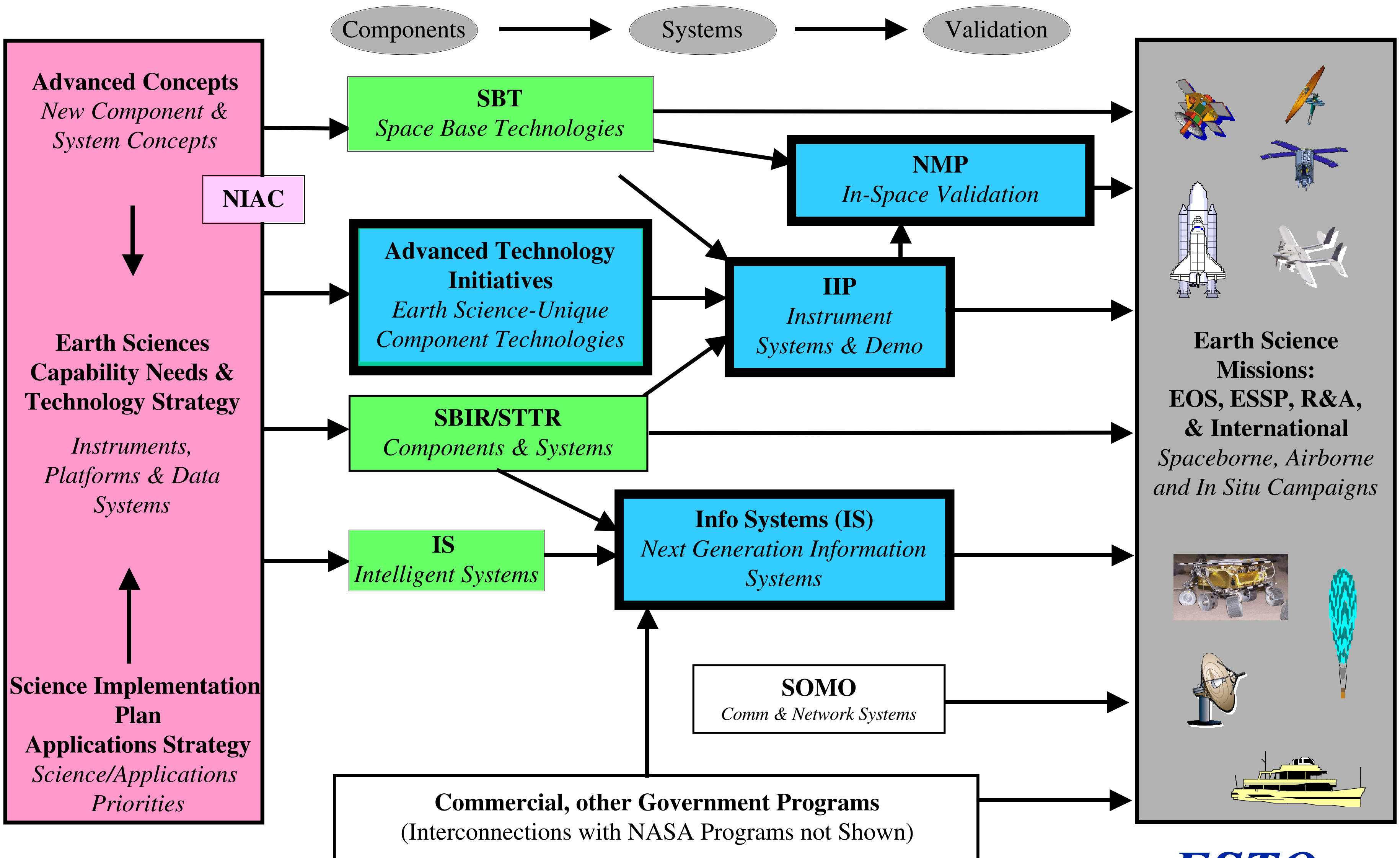
Enterprise objectives drive technology

Technology expands mission horizons

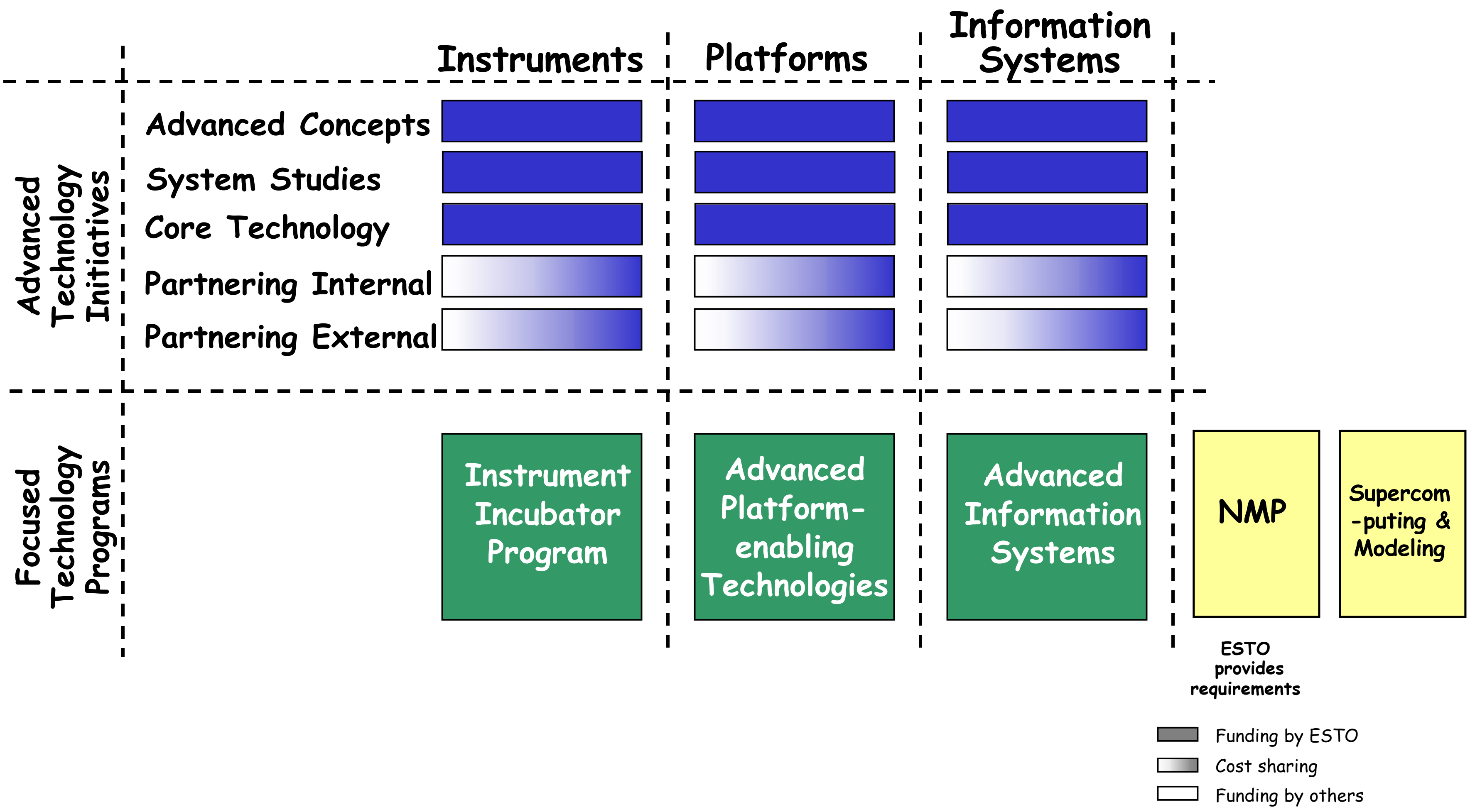
Missions evolve from convergence of objectives and technology


Deriving Measurement Requirements from the Research Strategy
Variability
Forcing
Response
Consequence
Prediction
Precipitation, evaporation & cycling of water changing?
Atmospheric constituents & solar radiation on climate?
Clouds & surface hydrological processes on climate?
Weather variation related to climate variation?
Weather forecasting improvement?
Global ocean circulation varying?
Changes in land cover & land use?
Ecosystem responses & affects on global carbon cycle?
Consequences in land cover & land use?
Transient climate variations?
Global ecosystems changing?
Surface transformation?
Changes in global ocean circulation?
Coastal region change?
Trends in long term climate?
Stratospheric ozone changing?
Stratospheric trace constituent responses?
Future atmospheric chemical impacts?
Ice cover mass changing?
Sea level affected by climate change?
Future concentrations of carbon dioxide and methane?
Motions of Earth & interior processes?
Pollution effects?
Requires both systematic & exploratory satellites
Requires systematic satellite observations
Requires exploratory satellite observations
Requires pre-operational and/or systematic/expl
Use available/new observations in better models

Technology Development Program Elements



ESTP Implementation

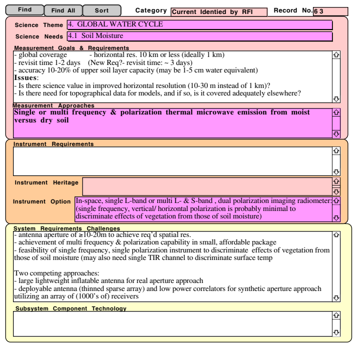


Strategic Process for Technology Development

What needs to be done?

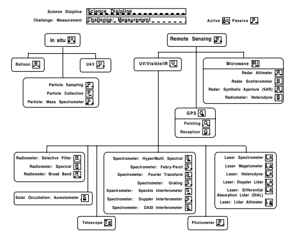
Science and Application Questions
Themes/Needs (Direct and Derived)
Goals/Requirements

Technology
Planning
Database



What approach?

Technology Approach



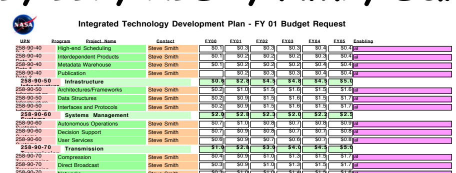
Active Instruments
Passive Instruments
Platforms
Info Systems

Gap Analysis

What and when we do it

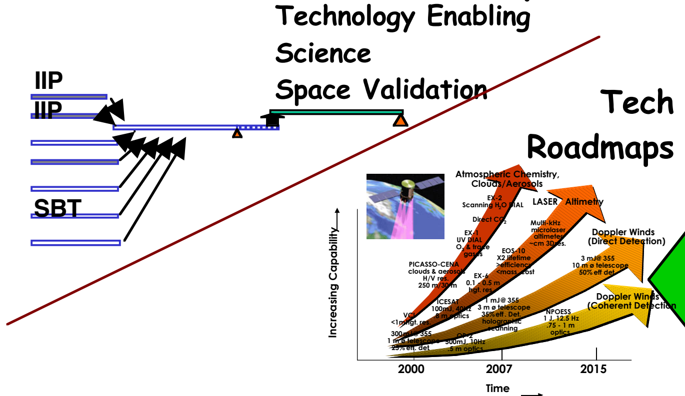
ITDP

Funded technology development
ATI, IIP, AIST, NMP, S&M



What tools?

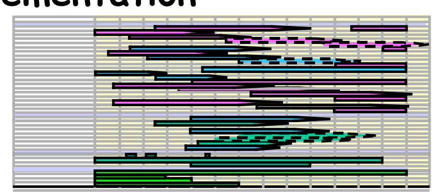
Measurement Scenario Roadmaps



Where we infuse?

Infusion Plan

Science & Applications
Implementation



ESTO
Earth Science Technology Office

ESTO Technology Investments

ESTO

GSFC (25)

IIP	5
ATI	6
AIST	2
Proto	7
TM	5

JPL (31)

IIP	9
ATI	7
AIST	8
Proto	1
TM	6

LaRC (10)

IIP	1
ATI	2
AIST	1
TM	6

Other NASA Centers (4)

ARC (AIST -1; Proto - 1)
GRC (AIST - 1; Battery - 1)

NOAA (1)

IIP - 1

National Labs (7)

Aerospace Corporation (ATI - 1)
DOE PNNL (Proto - 1)
JHU/Applied Physics Laboratories (IIP - 2)
Draper Laboratories (AIST - 1)
Naval Research Laboratories (AIST -1)
Sandia National Laboratories (IIP - 1)

Large Corps. (15)

BAE Systems (IIP-1)
Ball Aerospace (ATI - 2)
CSC (Proto - 1)
ITT Industries (AIST - 1; TM - 1)
Lockheed Martin (AIST - 1; Proto -1)
Orbital Sciences Corp. (IIP - 1)
RITSS (Proto - 4)
SAIC (AIST - 1)
TRW (AIST -1)

Small Corps. (16)

AstroPower, Inc. (TM - 1)
ElectroEnergy, Inc. (TM - 1)
EcoLogic (Proto - 1)
Fibertek, Inc. (ATI - 1)
GS&T, Inc. (Proto - 1; TM - 2)
Maxwell Technologies, Inc. (AIST - 1)
Pico Dyne, Inc. (AIST -1)
QSS, Inc. (AIST - 1; Proto -1)
SGT (Proto - 2)
Spaceborne, Inc. (ATI - 1)
Syagen Technology, Inc. (ATI -1)
Various Vendors (TM - 1)

Academia (28)

Clemson University (Proto - 1)
Colorado State U. (IIP - 1)
George Mason U. (Proto -2; TM - 1)
George Washington U. (TM - 1)
Howard University (AIST - 1)
Johns Hopkins University (ATI -1; TM - 1)
Morgan State U. (TM - 1)
Ohio State University (Proto - 1)
Ohio University (AIST - 1)
Rutgers University (IIP - 1)
Stanford University (ATI - 1)
UAH (AIST -2; Proto - 1; TM - 1)
U. of Arizona (IIP -2; AIST - 1)
U. of California, Berkeley (IIP - 1)
U. Of Kansas (IIP - 1; AIST -1)
U. Of Missouri (TM - 1)
U. Of Virginia (Proto - 1)
U. of Washington (AIST - 2)

IIP:	**27**
ATI:	**23**
AIST:	**30**
Prototyping:	**27**
Tech. Maturation:	**30**
Battery Earmark:	**1**
Total Awards:	**137**

Instrument Technology

CURRENT INVESTMENTS (IIP)

- 27 Contracts
  - 4 Active Optical
    - Laser, Lidar
  - 9 Passive Optical
    - Radiometer, Spectrometer
  - 4 Active Microwave
    - Radar, Altimeter
  - 7 Passive Microwave
    - Radiometer, GPS
  - 3 In situ

FUTURE INVESTMENTS (IIP)

- Active Remote Sensing
  - Lasers
  - Radars
- Radiometers

ADVANCED TECH INITIATIVES

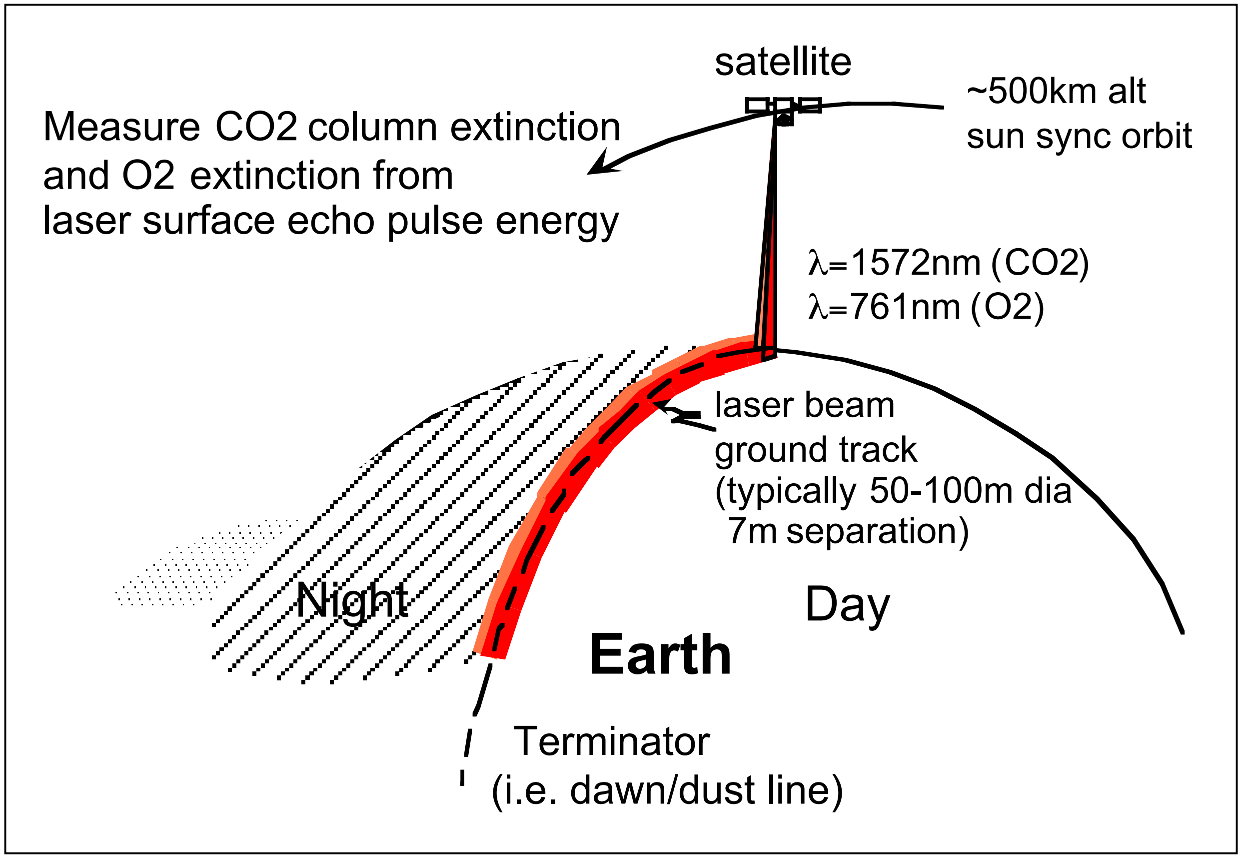
- 23 Contracts
  - 3 Far IR/Sub-millimeter wave
  - 4 Focal Plane Subsystem
  - 10 Laser
  - 4 Microwave Radar/Radiometer
  - 1 UV Radar/Radiometer
  - 1 Misc. Data Processing

ADVANCED CONCEPTS

- NIAC-funded Studies
- ESE Vision
  - Large ultra-lightweight deployable structures
  - Large aperture systems
  - Ultra-high resolution imaging
  - Rapid, low-cost sensor production
  - Biological sensors

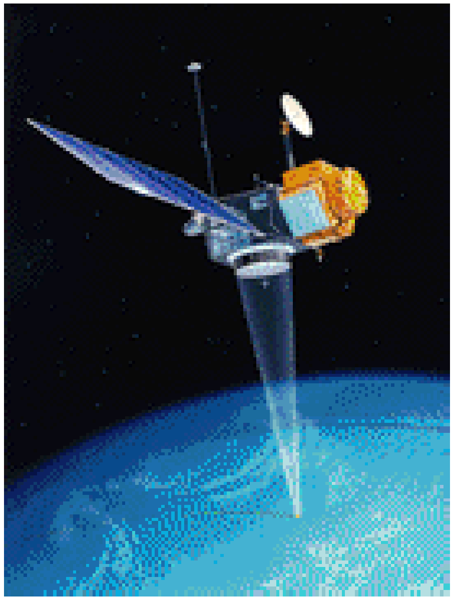
Laser Sounder Technology for Atmospheric CO_2 Measurements from Space

- **Measurement of CO_2 and O_2 column extinction from laser surface-echo pulse**



TRL=2

Ocean Altimetry Evolution



TOPEX/Poseidon

Description

TOPEX/Poseidon satellite orbits the earth about 830 miles above the surface. It carries a radar altimeter which measures the height of the sea surface to an accuracy of about 4 cm.

Vital Statistics

Payload weight – **2,500 kg**

Jason-1

Description

Jason is an oceanography mission to monitor global ocean circulation, improve global climate predictions, and monitor events such as El Niño conditions and ocean eddies. The Jason-1 satellite is a follow-on mission to the highly successful TOPEX/Poseidon mission.

Vital Statistics

Payload weight – **500 kg**

Design Life is 5 years

Instruments

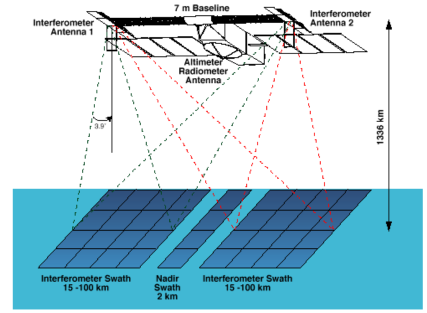
POSEIDON-2 – A solid state radar altimeter

DORIS – Doppler tracking system receiver

JMR – Microwave radiometer

TRSR – GPS tracking receiver

LRA – Laser retroreflector array



Future Ocean Altimetry Mission

Description

Integrate Altimeter/Radiometer/GPS into one instrument

- Reduce Mass/Power/Volume
- Simplify spacecraft Interfaces

Significant Increase in Science

- Global measurement of 2-D surface currents
- Full global sampling of ocean mesoscale eddies, which have the largest contribution to ocean kinetic energy spectrum

Vital Statistics

Payload weight – **100 kg**

Design Life is 5 years

TRL=3

Information Systems Technology

CURRENT INVESTMENTS (Prototyping)

- Interactive Access
- Open Distributed Architecture
- Storage Management Technology
- Prototype Management & Assessment
- Automated Systems Operations
- Network Prototypes

FUTURE INVESTMENTS (AIST)

- Data Collection Process
- Systems Management
- Transmission
- Infrastructure
- Analysis, Search & Display
- Data & Information Production

- AIST NRA:
  - On-board Satellite Data Processing and Intelligent Sensor Control
  - On-board Satellite Data Organization, Analysis and Storage
  - Data Transmission and Network Config.
  - Intelligent Platform Control
  - Information Systems Architectures and Standards
- SBT: Image mining: high rate rad hard digital modem
- External: Internet Protocol (IP) ver.6

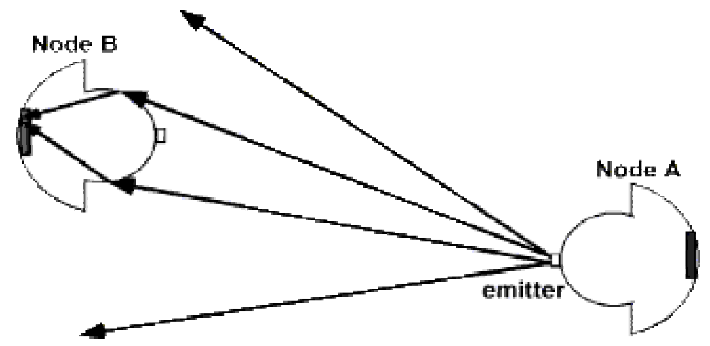
ADVANCED CONCEPTS

- ESE Vision
  - Autonomous, reconfigurable, adaptable, interactive sensor webs
  - Intelligent agents and sensors with pattern recognition
  - Neural networking
  - AI capabilities

Cat's Eye Modulating Retro-reflectors for Free Space Optical Data Transmission

Description and Objectives

Replace on-board hardwiring of electronic components with alignment tolerant free-space optical interconnects



Approach

Use quantum well based cat's eye modulating retro-reflector nodes to optically transmit information.

Schedule and Deliverables

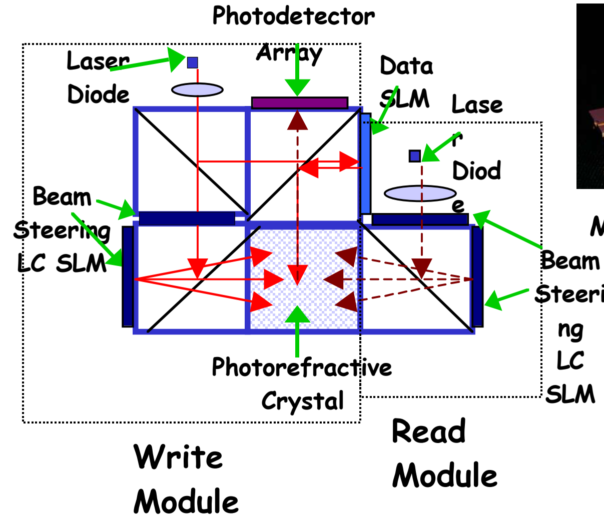
Year one: 4 Cat's Eye modulating retro-reflectors
Year two: Demonstration of free space link using CEMRRs

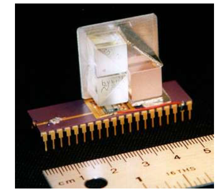
TRL=2

Advanced Holographic Memory

Description and Objectives

- Develop innovative holographic memory technology to enable real-time mass data storage/retrieval in space environment
- Demonstrate key capabilities:
  - High data storage capacity (up to 10GB/module)
  - High random access data transfer rate (up to 1GB/s)
  - Nonvolatile





Mark-up model

Approach

Employ new beam steering technology developed at JPL and phase conjugation architecture for a compact implementation of memory system.

Schedule and Deliverables

Initial system integration and proof-of-concept functionality demo: Aug '01

Lab compact breadboard data storage/retrieval performance evaluation demo: July '02

Application/Mission

Data intensive missions, including:

- Earth Science Missions, e.g., PM-2A, CHEM-2, NPOESS, METOP.
- Other data intensive missions, e.g., HEDS, SIM

TRL=2

Platform Technology

CURRENT INVESTMENTS

- None

FUTURE INVESTMENTS

- Advanced high bandwidth comm (optical)
- Low mass bus approaches: multifunctional Structures; low mass pmad power Generation; high efficiency propulsion
- Precision pointing systems (rotating antennas)
- Formation flying: autonomous control; precision ranging; s/c-s/c comm links
- New platform capabilities: micro mass systems for balloons and UAVS; environmentally protected systems and deployment options for buoys and penetrators.

ADVANCED TECH INITIATIVES

- Thermal coolers
- Mini Circuit Protection - SBIR
- Solar panel grid - SBIR
- Optical Comm
- Inflatable Membrane SAR
- Antenna Mesh
- Inflatable waveguide array
- IR Communication
- Remote Sensor Web
- ASIC
- Mobile Wireless - SBIR

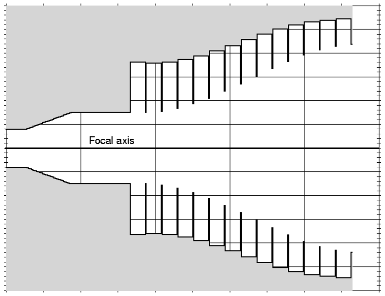
ADVANCED CONCEPTS

- Sensorcrafts
- Sensor webs

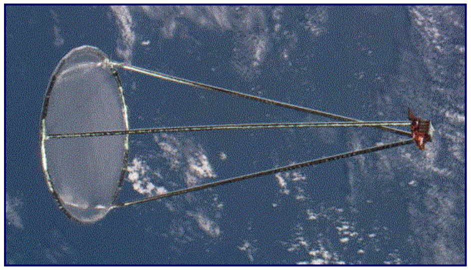
Large Aperture Mesh Antenna

Characteristics

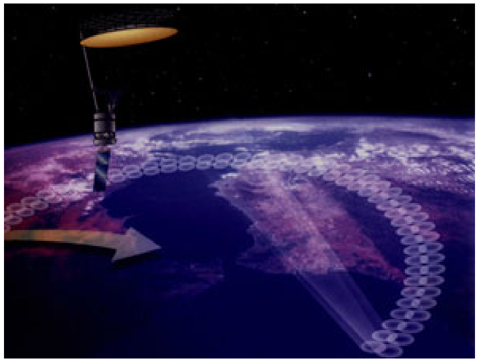
- Offset-fed, parabolic, deployable mesh reflector
- 6-m aperture
- 40° offset angle
- 6 rpm rotation rate
- 1.41 & 2.69 GHz, V, H, U (passive) (6 channels)
- 1.26 GHz; VV, HH, VH, HV (active) (4 channels)
- 2 multichannel feedhorns (L/S-band, V/H-pol)
- Feedhorn dimensions 0.6 x 0.6 x 0.9 m
- Approx. equal beamwidths all channels
- >90% beam efficiency, <-18dB cross-pol
- 1.2° pointing control (0.1° knowledge) (3s)



Corrugated feedhorn



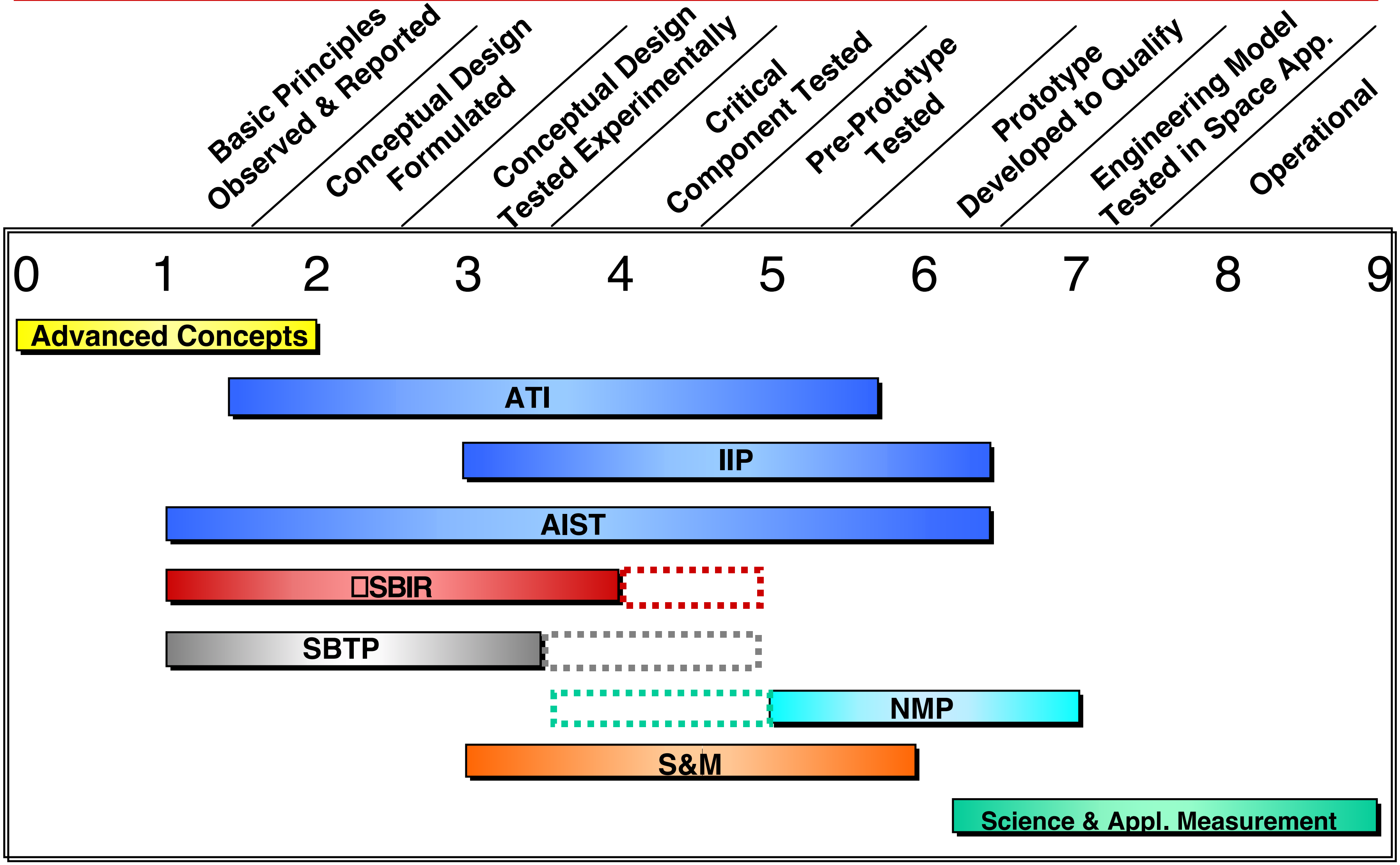
Large Deployable Mesh Antenna



System configuration

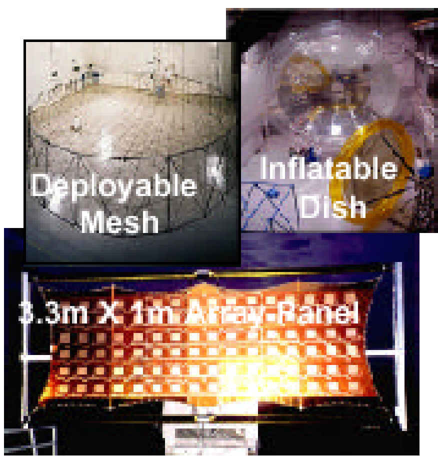
TRL=3

Technology Program Readiness

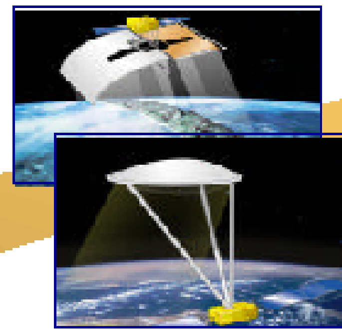


Development Roadmap for Large Antennas

- Large Deployable/Inflatable Antennas require testing in zero-G
  - deployment mechanism
  - surface shape/smoothness
  - structural control



Ground Tests



Validation Flight:

- *Validate deployment, rigidization, space survivability*
- *Structural accuracy/stability for 1 to >10 GHz*
- *Characterize vibration/thermal behavior*
- *Demonstrate material survivability*
- *Verify performance for radiometer*
- *Mass 50 kg (for antenna only)*

Science Measurements:

- *Soil Moisture*
- *Global Precipitation*
- *Topographic Hazards*
- *Sea Surface Salinity*

Capability

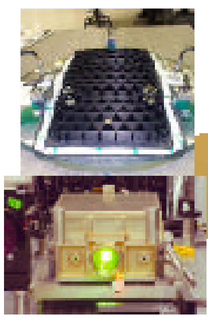
01 05 10

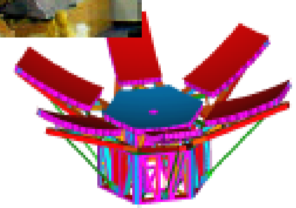
Development Roadmap for Lasers/Lidars

- Large Deployable telescope require zero-G testing of
  - deployment mechanism
  - surface shape/smoothness
  - surface controls
- High power lasers require testing in space
  - thermal issues
  - lifetime

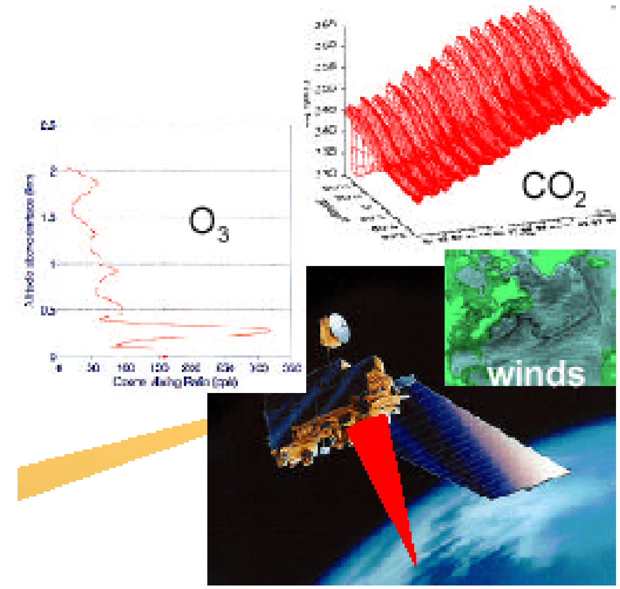
Telescope Size/Laser Power

Ground Development:
- *Deployable Telescope Components*
- *High Power Laser Transmitters*





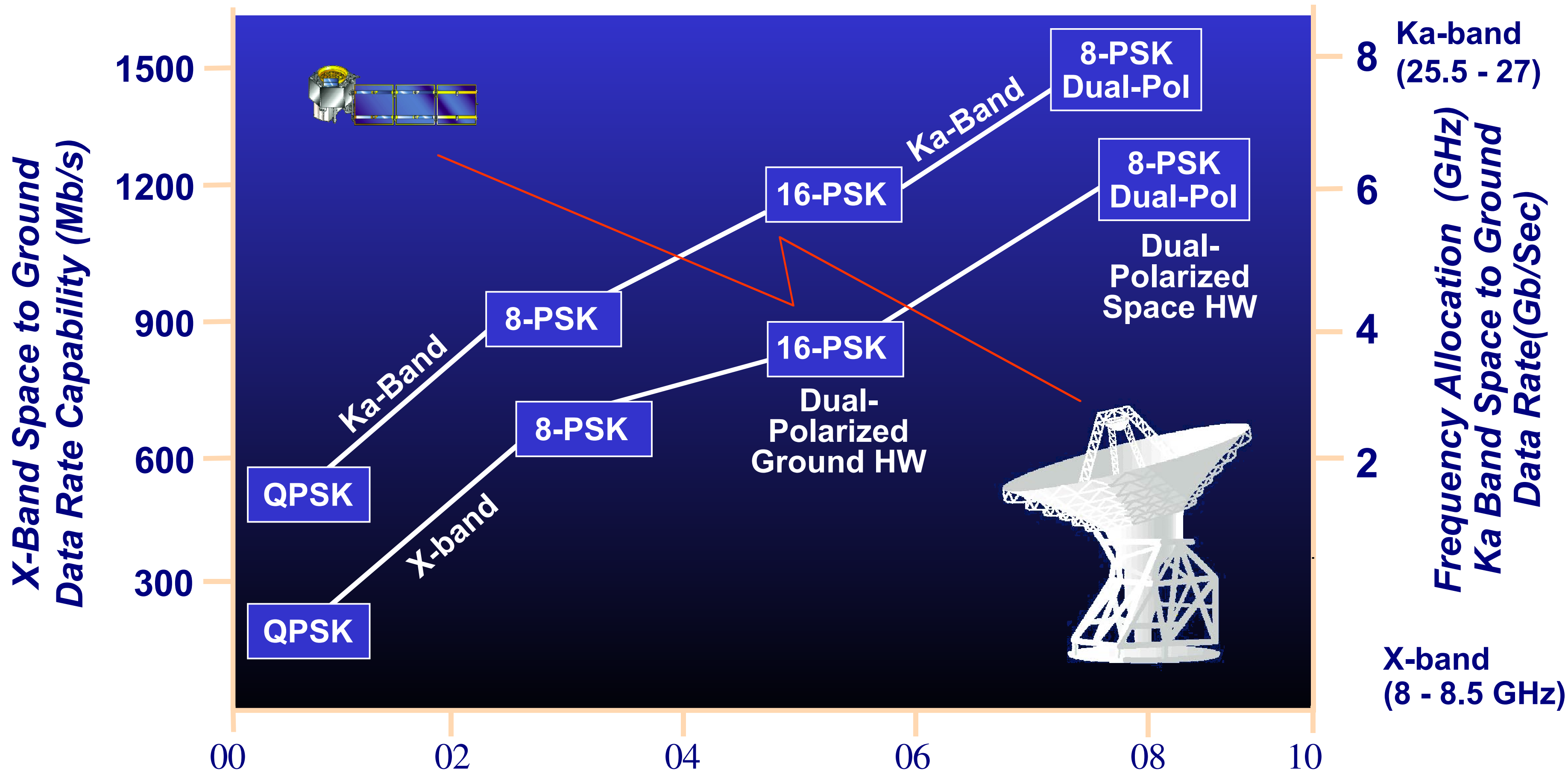
Validation Flights
- *Validate Laser performance and lifetime*
- *Validate telescope deployment and optical performance*



Science Measurements
- *Tropospheric Chemistry*
- *Atmospheric CO_2, CH_4, CO*
- *Tropospheric Winds*

2000 | 2005 | 2010

High Data Rate
Space to Ground Communications



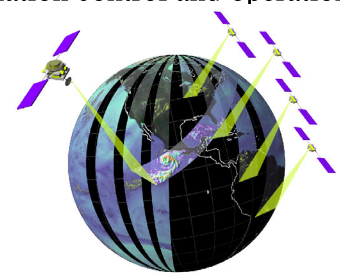
Integrated Technology Plan To Enable Global Precipitation Measurement

Objective:

- Provide systematic estimation of global precipitation with three hours or less sampling interval
  - •Improved weather forecasting
  - •Global water cycle understanding

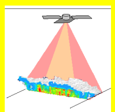
Technology Challenges:

- Phased Array Antenna
- Large aperture radiometers
- Integrated Observatory with autonomous constellation control and operation
- High rate cross-link/down-link
- Autonomous space/ground internet protocol



Instrument Incubator Program

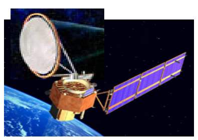
Imager



Radar

Global Precipitation Measurement Observation Strategy

Launch



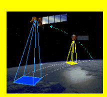
NMP Flight Validation

- **Cross Link**
- **Optical Communication**
- **Deployable Structure**

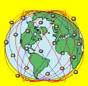
Launch

Other Technology Development Programs

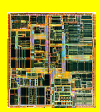
SBT - Lithium Ion Battery



Formation Flying



Constellation/Microsats



ESTO - Rad Hard Pentium Processor

Autonomous Internet Protocol

FY 00 | 01 | 02 | 03 | 04 | 05 | 06 | 07

Program Output

"Bang for the Buck"

NPOESS Preparatory Project

ESTO-supported technologies for infusion into NPP In-Situ Terminal:

1. Digital Demodulator ASIC (see next slide) is key technology component in digital receiver board. ESTO-funded ASIC final design and initial foundry run of chips which are now used in the operating board.

2. Reconfigurable Computing Application Development Environment (RCADE) tools evolved *directly* from ESTO Prototyping Program[1]:

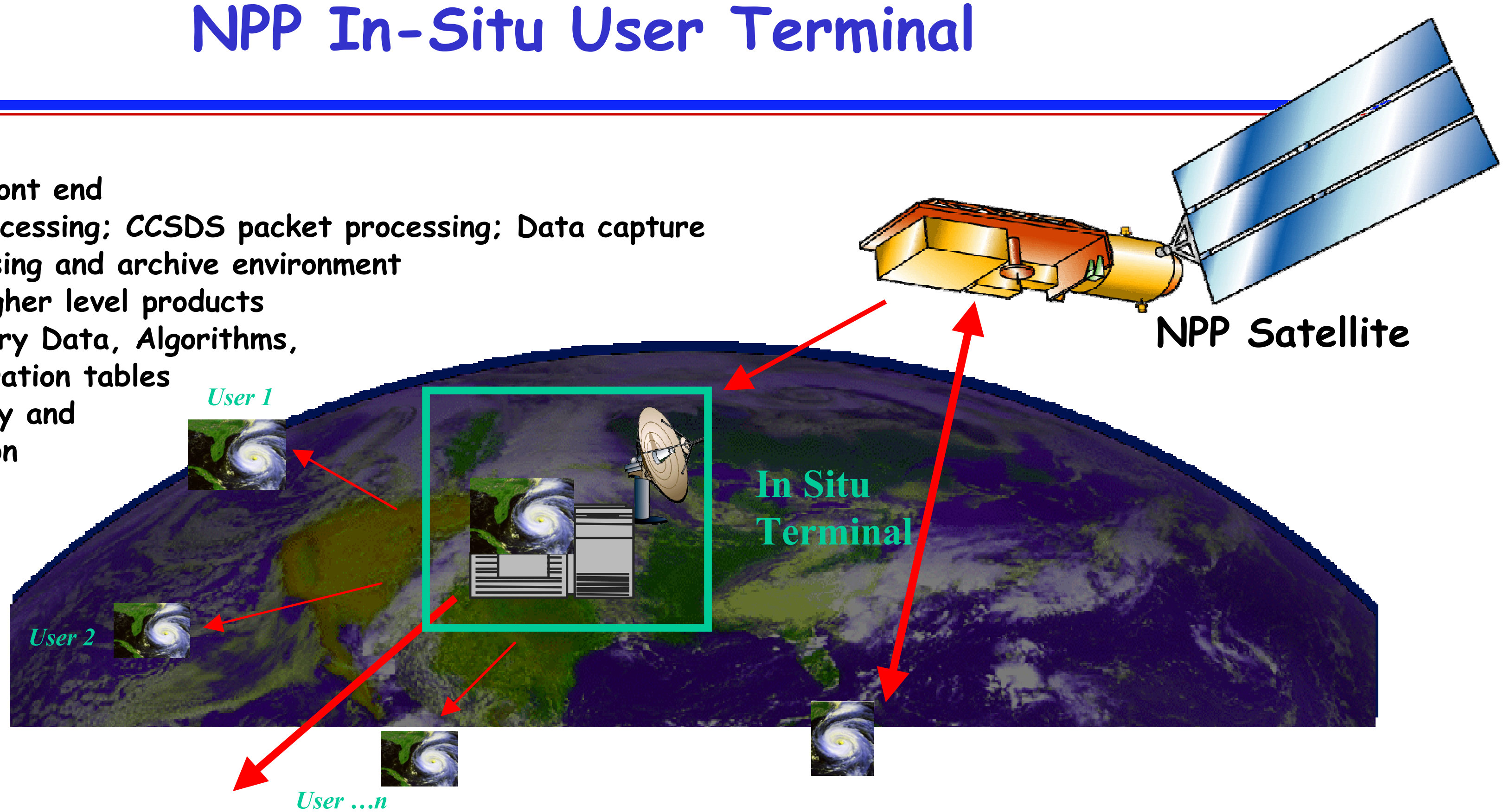
   - Allows rapid integration of ESE data processing algorithms into FPGAs.
   - Testing of FPGA processing using Terra MODIS data has already begun. Major bottleneck is re-programming the FPGAs when the algorithms are updated.
   - ESTO tool-set is designed to address this *exact* problem.

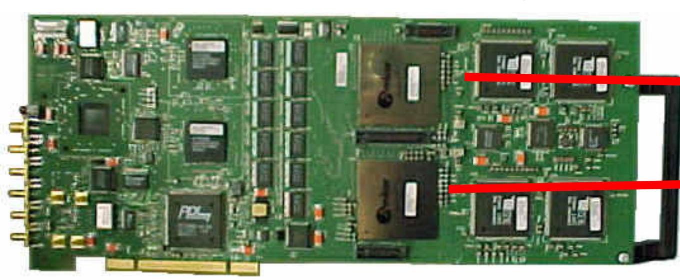
1. "Scalable Remote Sensing Applications" which is a Parallel Problem Solving Environment (PSE) for Remote Sensing and Telemetry Processing.

NPP In-Situ User Terminal

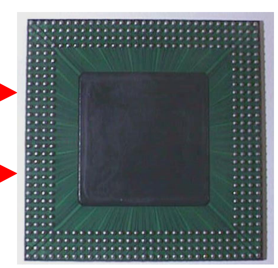
Features:

- High rate front end
  - RF processing; CCSDS packet processing; Data capture
- Data processing and archive environment
- Level 1B, higher level products
  - Ancillary Data, Algorithms, Calibration tables
- Product query and distribution





NPP Digital Receiver Board



ESTO Digital De-Modulator ASIC

Precise Global Real-time Onboard Navigation Capability For Earth Science Remote Sensing

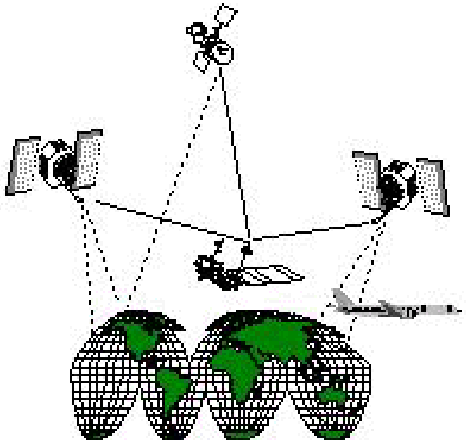
PI: Yoaz Bar-Sever / JPL

Description and Objectives

Develop GPS-based technology that will enable:

- Ultra-precise real-time orbit determination
- Global uniform coverage extending into space
- Autonomous navigation

Demonstrate an end-to-end NASA global differential system and its scientific benefits



Approach

Extend JPL's Wide Area GPS differential Technology to a global scale

Develop end-user hardware and software to enable autonomous navigation

Leverage NASA's GPS infrastructure and commercial capabilities to demonstrate a global differential GPS service

Application/Mission

Timely monitoring and response to natural hazards (e.g., SAR, AirSAR)

Intelligent, cooperating sensor webs in Earth orbit

Precise and secure navigation (e.g., RLV)

Prototype for Mars Network

Current Payoff

- (NavCom, Inc., a subsidiary of John Deere), has signed an agreement to provide correction data….

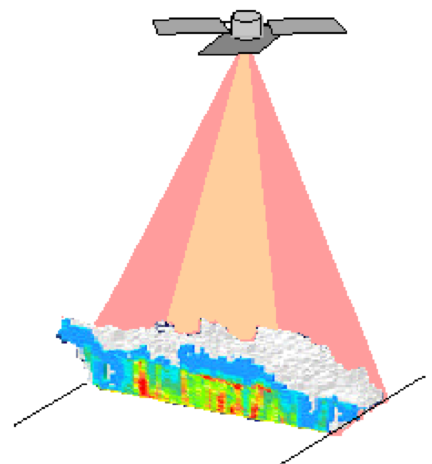
- System status
  - We have a signal. A "beta" signal is now available over North and South America for test and characterization, using a global beam of an Inmarsat Satellite.
  - Preliminary tests show the signal is received clearly in North America. The signal is based on the corrections to the GPS orbits and clocks generated at JPL.

A Second generation Spaceborne Precipitation Radar

Characteristics

Dual-frequency to improve dynamic range and sensitivity on rain measurements (TRMM radar has 1 frequency)

- Factor of two improvement in radar resolution to reduce errors caused by rain inhomogeneity
- Dual polarization to differentiate between liquid and frozen hydrometeors (TRMM radar has single polarization)
- Doppler capability to obtain vertical motion structure (TRMM radar none)
- Simultaneous doppler/polarization observations to constrain implicit rain ambiguity (TRMM radar makes reflectivity-only observations)
- Cross-track adaptive scan to increase swath coverage (a factor of 3 better than TRMM radar)
- Same frequency as TRMM radar to allow smooth extension and direct comparison of rain data record
- A factor of 2 to 3 mass reduction from TRMM radar



Airborne Demonstrator Precursor

- Mechanically scanned, horn fed reflector
- TWTA transmitters
- Ferrite T/R and polarization switches
- Dual-frequency (13.405 and 35.605 Ghz)
- Dual-linear Polarization at each frequency
- Scan Beam Capability 0-20 Degrees
- Match Beamwidths at Each Frequency/Polarization of Operation to Within 25%
- Antenna Patterns Sidelobe Level < -25 dB
- VSWR < 1.6
- Bandwidth at Each Frequency/Polarization > 10 MHz

PR-2 Airborne Payoff

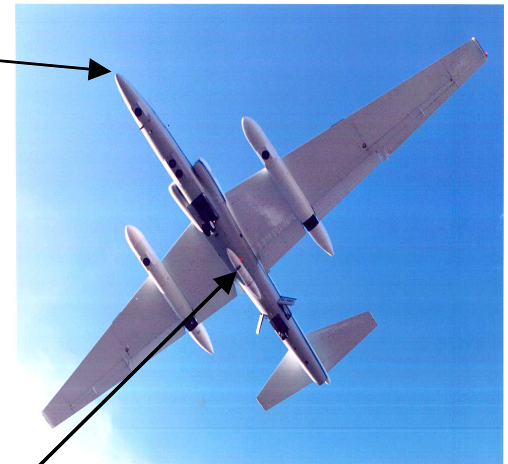
- PR-2 (airborne) was selected to fly on the DC-8 during the CAMEX-4, a multi-agency field campaign to study hurricanes in August 2001.
- It will provide measurements of rain rate.
- PR-2 (airborne) will improve measurement capability over current systems
  - Dual-frequency (14/35 GHz) to improve dynamic range and sensitivity on rain measurements
  - Factor of two improvement in radar resolution to reduce errors caused by rain inhomogeneity
  - Dual polarization to differentiate between liquid and frozen hydrometeors
  - Doppler capability to obtain vertical motion structure
  - Cross-track adaptive scan over ±37° to increase swath coverage
- PR-2 (airborne) is a precursor demonstration of capability for GPM/ generation 2.

HAMSR: High Altitude MMIC Sounding Radiometer

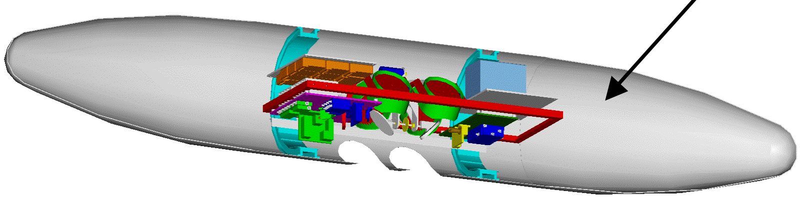
Objectives

- Build millimeter-wave atmospheric sounder using new miniature technology
  - Temperature and water vapor sounding capabilities (54, 118 & 183 GHz)
  - First MMIC based atmospheric sounder (54 & 118 GHz)
  - Reduced size/mass/power (fraction of AMSU)
- Operate prototype in the field on board ER-2

Revised HAMSR Mounting in ER2 Nose

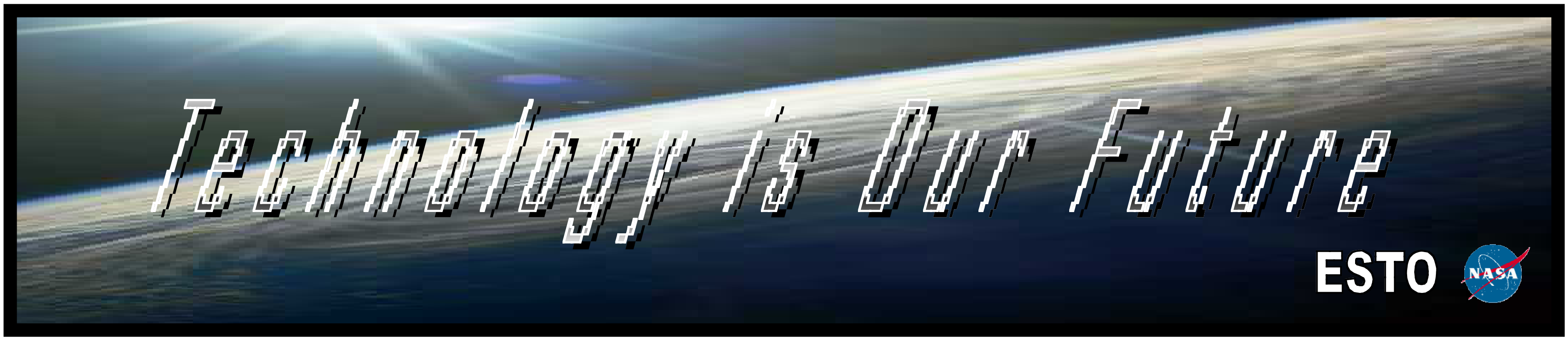


Original concept HAMSR Mounting in ER2 Fuselage Pod



HAMSR Payoff

- HAMSR was selected to fly on the NASA ER-2 during the CAMEX-4, a multi-agency field campaign to study hurricanes in August 2001.
- It will provide core measurements of temperature, humidity, liquid water profiles as well as scattering from rain and ice.
- HAMSR is the first sounder to use new miniature MMIC technology, developed by NASA and integrated into a functional instrument under IIP.
- HAMSR is the only instrument to combine this measurement suite in a single, small package


Technology is Our Future
ESTO